STATISTICAL CHARACTERIZATION OF ALTITUDE MATRICES BY COMPUTER

REPORT 5

Terrain analysis : program documentation

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THE FIFTH PROGRESS REPORT ON GRANT DA-ERO-591-73-G0040

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CONTENTS

AIM

The terrain analysis system of programs derives, from a matrix of altitude data, the descriptive characteristics of gradient, aspect, and profile and plan convexity for the central point of each 3x3 square set of adjacent grid points. The characteristics are derived algebraically from a quadratic fitted by the least squares method to each set of 9 points. For the whole matrix, the mean, standard deviation, skewness and kurtosis are found for the calculated altitude, gradient and profile and plan convexities. The vector mean of the aspect is found and also the regression of each of the other characteristics with the sine and cosine of the aspect. The descriptive characteristics are displayed in several ways, viz, histograms, scatter diagrams and line printer density maps. A map is produced on the graph plotter giving the direction and magnitude of the gradient at each grid point. The programs are written in FORTRAN; they call SPSS and MIDAS routines and run under the MTS system on the NUMAC IBM 370/168 computer. The system and the special programs were written by Margaret and Tony Young, to specifications by Ian S. Evans. Reasons for these specifications are given in the Final Report.

MATHEMATICAL DERIVATIONS

Input data The program has been designed to accept a rectangular matrix of altitude data. It assumes that the data are derived from points equally spaced in the north-south and east-west directions, that the first row is the northernmost, and that it is to be read from west to east. The program requires the distance in metres between grid points, the number of columns in the matrix of data and a scaling factor to convert the altitudes to metres. For an irregular area such as a drainage basin, the remaining grid points within an enclosing rectangle are given as zero and any set of 3x3 points which contains a zero is ignored.

Least squares equation For each 3x3 square of grid points a quadratic equation is fitted by the method of least sum of squared deviations. Let this be:

$$z = ax^2 + by^2 + cxy + dx + ey + f$$

and let the mesh points of the grid be g metres apart. Then the least squares solution is obtained by solving the standard matrix equation:

$$F^T F\alpha = F^T z$$

where α is the 6x1 matrix $\begin{pmatrix} a \\ b \\ c \\ d \\ e \\ f \end{pmatrix}$

and z is the 9x1 matrix of heights at the 9 grid points

$$\begin{matrix} (-g,g) & (0,g) & (g,g) \\ (-g,0) & (0,0) & (g,0) \\ (-g,-g) & (0,-g) & (g,-g) \end{matrix}$$

The matrix F is thus given by:

$$F = \begin{pmatrix} g^2 & g^2 & -g^2 & -g & g & 1 \\ 0 & g^2 & 0 & 0 & g & 1 \\ g^2 & g^2 & g^2 & g & g & 1 \\ g^2 & 0 & 0 & -g & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ g^2 & 0 & 0 & g & 0 & 1 \\ g^2 & g^2 & g^2 & -g & -g & 1 \\ 0 & g^2 & 0 & 0 & -g & 1 \\ g^2 & g^2 & g^2 & g & -g & 1 \end{pmatrix}$$

and $\alpha = (F^TF)^{-1}F^Tz$. $(F^TF)^{-1}F^T$ is found to be :

$$\begin{pmatrix} \frac{1}{6g^2} & \frac{-1}{3g^2} & \frac{1}{6g^2} & \frac{1}{6g^2} & \frac{-1}{3g^2} & \frac{1}{6g^2} & \frac{1}{6g^2} & \frac{-1}{3g^2} & \frac{1}{6g^2} \\ \frac{1}{6g^2} & \frac{1}{6g^2} & \frac{1}{6g^2} & \frac{-1}{3g^2} & \frac{-1}{3g^2} & \frac{-1}{3g^2} & \frac{1}{6g^2} & \frac{1}{6g^2} & \frac{1}{6g^2} \\ \frac{-1}{4g^2} & 0 & \frac{1}{4g^2} & 0 & 0 & 0 & \frac{1}{4g^2} & & \frac{-1}{4g^2} \\ \frac{-1}{6g} & 0 & \frac{1}{6g} & \frac{-1}{6g} & 0 & \frac{1}{6g} & \frac{-1}{6g} & 0 & \frac{1}{6g} \\ \frac{1}{6g} & \frac{1}{6g} & \frac{1}{6g} & 0 & 0 & 0 & \frac{-1}{6g} & \frac{-1}{6g} & \frac{-1}{6g} \\ \frac{-1}{9} & \frac{2}{9} & \frac{-1}{9} & \frac{2}{9} & \frac{5}{9} & \frac{2}{9} & \frac{-1}{9} & \frac{2}{9} & \frac{-1}{9} \end{pmatrix}$$

As the matrix is only evaluated once it is neater to use this form rather than to compute it and store the coefficients.

Derivation of descriptive characteristics   The gradient, aspect, profile (or vertical) convexity and plan (or horizontal) convexity are derived from the quadratic:

$$z = ax^2 + by^2 + cxy + dx + ey + f$$

Also if $\left.\begin{array}{l} x = r\cos\Theta \\ y = r\sin\Theta \end{array}\right\}$ this transforms to

$$z = r^2(a\cos^2\Theta + b\sin^2\Theta + c\sin\Theta\cos\Theta) + r(d\cos\Theta + c\sin\Theta) + f$$

The gradient of the origin (central point) is given by:

$$\left(\frac{dz}{dr}\right)_{r=0} = 2r(a\cos^2\Theta + b\sin^2\Theta + c\sin\Theta\cos\Theta) + d\cos\Theta + e\sin\Theta$$

$$= d\cos\Theta + e\sin\Theta \quad (= G \text{ say})$$

For max. or min. $\frac{dG}{d\Theta} = 0$, i.e. $-d\sin\Theta + e\cos\Theta = 0$, or $\tan\Theta = \frac{e}{d}$

which gives the aspect angle, Θ.

The standard two-dimensional expression for curvature is:

$$\frac{1}{\rho} = \frac{d^2y}{dx^2} \Big/ \left\{1 + \left(\frac{dy}{dx}\right)^2\right\}^{3/2}$$

Using the convention that convex surfaces have positive, and concave surfaces have negative curvature, this gives:

$$\text{Plan curvature (plan c)} = \frac{-d^2y}{dx^2} \Big/ \left\{1 + \left(\frac{dy}{dx}\right)^2\right\}^{3/2}$$

$$\text{and Profile curvature (prof c)} = \frac{-d^2r}{dz^2} \Big/ \left\{1 + \left(\frac{dr}{dz}\right)^2\right\}^{3/2}$$

for prof c

$$\frac{dz}{dr} = 2r(a\cos^2\Theta + b\sin^2\Theta + c\sin\Theta\cos\Theta) + d\cos\Theta + e\sin\Theta$$

$$\frac{d^2z}{dr^2} = 2(a\cos^2\Theta + b\sin^2\Theta + c\sin\Theta\cos\Theta)$$

and as $\tan\Theta = \frac{e}{d}$, $\cos\Theta = \frac{d}{(e^2+d^2)^{\frac{1}{2}}}$ and $\sin\Theta = \frac{e}{(e^2+d^2)^{\frac{1}{2}}}$

which gives:

$$\underset{(r=0)}{\text{prof } c} = \frac{-2(a\cos^2\Theta + b\sin^2\Theta + c\sin\Theta\cos\Theta)}{\{1 + (d\cos\Theta + e\sin\Theta)^2\}^{3/2}}$$

$$= \frac{-2(ad^2 + be^2 + ced)/(e^2 + d^2)}{\{1 + (d^2 + e^2)^2/(e^2 + d^2)\}^{3/2}}$$

$$= \frac{-2\,(ad^2 + be^2 + ced)}{(e^2 + d^2)(1 + d^2 + e^2)^{3/2}}$$

For plan c

$$ax^2 + by^2 + cxy + dx + ey + f = \text{const.}$$

differentiating with respect to x gives:

$$2ax + 2by\frac{dy}{dx} + cy + cx\frac{dy}{dx} + d + e\frac{dy}{dx} = 0$$

$$\therefore \frac{dy}{dx} = \frac{-(2ax + cy + d)}{2by + cx + e}$$

$$\text{At } (0,0)\ \frac{dy}{dx} = \frac{-d}{e}$$

$$\frac{d^2y}{dx^2} = -\left\{\frac{(2ax + cy + d)(2b\frac{dy}{dx} + c) - (2by + cx + e)(2a + \frac{cdy}{dx})}{(2by + cx + e)^2}\right\}$$

$$\therefore \text{at } (0,0)\ \frac{d^2y}{dx^2} = -\frac{d((\frac{-d}{e})2b + c) - e(2a + c(\frac{-d}{e}))}{e^2}$$

$$= \frac{2}{e^3}(bd^2 + ae^2 - cde)$$

$$\text{Now plan } c = -\frac{d^2y}{dx^2} / \{1 + (\frac{dy}{dx})^2\}^{3/2}$$

$$\therefore \text{plan } c \text{ at } (0,0) = -2\frac{(bd^2 + ae^2 - cde)}{e^3(1 + d^2/e^2)^{3/2}}$$

$$= 2\frac{(bd^2 + ae^2 - cde)}{(e^2 + d^2)^{3/2}}$$

Conditions for zero gradient points

For a function $z=f(x,y)$ to have zero gradient

$$\frac{\partial z}{\partial x} = 0 \quad \text{and} \quad \frac{\partial z}{\partial y} = 0$$

For the quadratic $ax^2 + by^2 + cxy + dx + ey + f = z$, zero gradient occurs at a point x,y given by:

$$\frac{\partial z}{\partial x} = 0 = 2ax + cy + d$$

$$\frac{\partial z}{\partial y} = 0 = 2by + cx + e$$

$$\text{i.e.} \qquad x = \frac{ec - 2bd}{4ab - c^2} \;, \qquad y = \frac{dc - 2ae}{4ab - c^2}$$

The condition for a saddle point is:

$$\frac{\partial^2 z}{\partial x^2} \cdot \frac{\partial^2 z}{\partial y^2} - \left(\frac{\partial^2 z}{\partial x \partial y}\right)^2 < 0$$

i.e. $2a \cdot 2b - c^2 < 0$

i.e. $4ab < c^2$

For a maximum or a minimum:

$$\frac{\partial^2 z}{\partial x^2} \cdot \frac{\partial^2 z}{\partial y^2} - \left(\frac{\partial^2 z}{\partial x \partial y}\right)^2 > 0$$

i.e. $4ab > c^2$

If $\frac{\partial^2 z}{\partial x^2}, \frac{\partial^2 z}{\partial y^2} < 0$ the point is a maximum

If $\frac{\partial^2 z}{\partial x^2}, \frac{\partial^2 z}{\partial y^2} > 0$ the point is a minimum

The above conditions are general and could be used to determine zero gradient points away from the point $(x=0,y=0)$ to which all the calculations in the analysis program refer.

Description of zero gradient points At the central point in some cases (most commonly for lakes) the values calculated for d and e are both zero, i.e. the gradient is zero and the aspect is vertical, and thus the aspect angle is indeterminate. As a complete set of characteristics does not exist for such a point, no values are stored for inclusion in the main statistics. It is possible to find the shape of terrain at such a point by calculating profile convexity and the maximum and minimum values determine this shape as follows:

For d=0 and e=0

use $\dfrac{d^2z}{dr^2} = 2(a\cos^2\Theta + b\sin^2\Theta + c\cos\Theta\sin\Theta)$

This can be written: $2(A\cos(2\Theta + B) + C)$

where $$A\cos(2\Theta + B) + C = A(\cos 2\Theta\cos B - \sin 2\Theta\sin B) + C$$

$$= A\cos B(\cos^2\Theta - \sin^2\Theta) - A\sin B(2\sin\Theta\cos\Theta) + C(\sin^2\Theta + \cos^2\Theta)$$

$$= A(\cos B + C)\cos^2\Theta + (C - A\cos B)\sin^2\Theta - 2A\sin B\cos\Theta\sin\Theta$$

i.e. $a = A\cos B + C$

$b = C - A\cos B$

$c = -2A\sin B$

giving $C = \dfrac{a + b}{2}$

$A\cos B = \dfrac{a - b}{2}$

$A\sin B = -\dfrac{c}{2}$

giving $$A^2 = \left(\frac{a - b}{2}\right)^2 + \left(\frac{c}{2}\right)^2 = \frac{(a - b)^2 + c^2}{4}$$

and $\tan B = \dfrac{c}{b - a}$

For gradient = 0

$$\text{prof c} = -\frac{d^2z}{dr^2}$$

$$= -2(A\cos(2\Theta + B) + C)$$

Max prof c $= -2C + 2|A| = -(a + b) + ((a - b)^2 + c^2)^{\frac{1}{2}}$

Min prof c $= -2C - 2|A| = -(a + b) - ((a - b)^2 + c^2)^{\frac{1}{2}}$

For the cases when the surface is a horizontal plane, i.e. a plain or lake,

$a = b = c = d = e = 0$ i.e. $A = C = 0$

For a <u>summit</u>, i.e. convex surface

prof c > 0 for all Θ

i.e. $|A| < |C|$ and $C < 0$ $c^2 < 4ab$ and $a + b < 0$

For a <u>ridge</u>

prof c ≥ 0 for all Θ

i.e. $|A| = |C|$ and $C < 0$ $c^2 = 4ab$ and $a + b < 0$

For a <u>saddle</u>

prof c has positive and negative values

i.e. $|A| > |C|$ $c^2 > 4ab$

For a <u>valley</u>

prof c ≤ 0 for all Θ

i.e. $|A| = |C|$ and $C > 0$ $c^2 = 4ab$ and $a + b > 0$

For a <u>pit</u>

prof c < 0 for all Θ

i.e. $|A| < |C|$ and $C > 0$ $c^2 < 4ab$ and $a + b > 0$

Thus the maximum and minimum values of prof c give the shape of the terrain as follows:

max >0	min >0	summit
max >0	min =0	ridge
max >0	min <0	saddle
max =0	min =0	plain
max =0	min <0	valley
max <0	min <0	pit

Other methods of detecting topographic features are given by Peucker and Douglas (1975) and Grender (1976).

PROGRAM DESCRIPTIONS

The main program The main program fits the least squares quadratic and calculates the descriptive characteristics gradient, aspect and the profile and plan convexities. Initially the program reads in and scales two rows of altitude data, and subsequently one row at a time. Using three rows it tests for zero values then calculates the characteristics for each point in the row. If a test for zero gradient is positive, the altitude and maximum and minimum values of profile convexity are printed, with a description of the type of point. Such points are not included in the main statistics as values of the characteristics are not complete. However, sums of squares and higher products of altitude are stored separately for additional statistics.

The characteristics for non-zero gradient points are stored in a file for use by other programs. The sum of squares and cross products are calculated for the statistics. Double length working is used for the sums of squares and higher products as loss of accuracy is possible when forming sums of up to 40,000 points, particularly for the higher moments. When the end of the altitude data is reached the program calculates (for non-zero gradient points) the mean, standard deviation and the skew and kurtosis, and also correlation coefficients for calculated height, gradient (which is expressed in degrees) and profile and plan convexities (which are in degrees per 100m). Mean, standard deviation, skewness and kurtosis are calculated for all points for the characteristics calculated height and gradient, and for plain and non-zero gradient points for prof c and plan c. The vector mean of the aspect, and the vector mean of the aspect weighted by the gradient, are also calculated. The statistics are printed and the means, standard deviations, maxima and minima are stored for use by other programs.

The main program calls several specially-written programs and parts of the SPSS and MIDAS packages.

The mapping programs One of the ways in which the characteristics are displayed is a series of line printer maps. The value of a characteristic at each grid point is indicated by the density of printing. A blank space indicates a missing value at that point, due either to the shape of the area or to a point of zero gradient for which some characteristics do not exist. In aspect data 8 density values are used, the darkest indicating north and the lightest south, while east and west directions have printer characters different in form but similar in density.

Multiple regression and histograms The SPSS and MIDAS programs available in the NUMAC system are used for multiple regression, scatter diagrams and histograms. SPSS is called to produce the following regressions:

Calculated height, gradient, profile convexity and plan convexity each as functions of sine and cosine of aspect.

Gradient as a function of calculated height, square of calculated height, sine and cosine of aspect.

Profile and plan convexity each as functions of calculated height, gradient, sine and cosine of aspect.

These combinations were chosen as interpretable sets of controlling variables, influencing the (first-named) dependent variable.

SPSS is also used to produce scatter diagrams of each pair of the following: calculated height, aspect, gradient, profile convexity and plan convexity.

The SPSS scattergram program prints the number of values at each position up to a maximum of 9 - some detail is lost in this way but the shapes of the distributions can easily be seen.

The MIDAS programs are called to produce a histogram of each characteristic. The limits and scales to be used by this program are calculated by the limits program.

Slope plotting program The slope plotting program produces a map showing the direction and magnitude of the gradient at each grid point. For each point for which the gradient is not zero an arrow is plotted, with the centre of its shaft at the grid point. The direction of the arrow indicates the line of maximum gradient, and the shaft is one of 5 different lengths depending upon the magnitude of the gradient.

Class limits As the system of programs is designed to analyse data from a wide variety of different types of terrain, it is impossible to determine in advance the class boundaries and limits which will produce acceptable maps and histograms. This is especially true for altitude where the variation can be as little as 20 metres or over 1,000. For the histograms produced by the MIDAS program the height interval is chosen to produce between 60 and 120 classes, with a range from just below the minimum to just above the maximum. In the density maps (apart from the aspect map which has 8 fixed limits), 6 densities are used and it is necessary to choose limits which give similar numbers of points for each density value. For altitude and gradient the points of division between classes use the mean and standard deviation (sd) as follows:

mean −1.2sd , mean −0.6sd , mean, mean +0.6sd , mean +1.2sd

which for a normal distribution give a fairly even distribution between classes (Evans, 1977).

For gradient, a map using fixed limits was also produced to facilitate comparison of different matrices.

Organisation The complete analysis of an altitude matrix requires several programs to be called using data mainly produced by the main program. The SPSS and MIDAS programs require a specified format for the data. This was achieved by creating a master file containing all the run commands and all the information for each program. An organisation program to calculate the limits and class boundaries was written. This program reads data from a specified file, calculates the limits and writes these back into the master file in the required format. As several programs require the same data, i.e. title, file names, etc., these are read into part of the master file and picked up as required. These are:

Title of run
Name of file containing altitude matrix
Name of file for detailed results - this is usually dummy
Name of file (possibly temporary) for storage of characteristics, gradient aspect, etc., to be used by other programs
Name of file for limits
Grid size in metres
Scaling factor for heights
Number of columns in altitude matrix
Format of data

The files for results and limits must be empty initially; if the same files are used for several runs they must be emptied before each run.

PROGRAM DETAILS AND RUNNING INSTRUCTIONS

Main program OMY8 The main program accepts a rectangular matrix of altitude data together with a scaling factor. Using the standard least squares method it fits a quadratic to sets of 3x3 adjacent points, and from the quadratic it derives the calculated altitude, gradient, aspect, profile convexity and plan convexity for each point. For the whole matrix the mean, standard deviation, skewness and kurtosis of the characteristics are calculated, as are correlations between calculated altitude, gradient, profile convexity and plan convexity.

Input: Cards A-I

A Data header (20A4)

B Name of file containing altitude matrix

C Name of file for output of detailed results (usually DUMMY)

D Name of file for storage of calculated values for use by other programs

E Name of file for storage of maximum and minimum values for use by the limits program

F Distance in metres between grid points of altitude matrix

G Scale factor. Each value in the altitude matrix is multiplied by this scale factor to convert each altitude to metres (F10.3)

H Number of columns in the altitude matrix (I4)

I Format of data in altitude matrix

For items B,C,D,E the name of the file must start in column 1 and be followed by at least one space.

The altitude data is assumed to be in the form of a rectangular matrix of altitudes derived from a grid of points equally spaced in the N-S and E-W directions. The first row is taken as the northernmost and is read from west to east. If any zero or negative value is encountered in the altitude data it is assumed that the value is not valid and it is rejected from the calculations.

From each 3x3 set of adjacent altitude points the following are calculated for the central point:

Calculated height of the quadratic in metres
Aspect angle of the slope measured in degrees clockwise from north
Gradient of maximum slope measured in degrees below horizontal
Profile convexity measured in degrees/100m
Plan convexity measured in degrees/100m

These values are stored for use by other programs and sums of powers 1 to 4 and of cross products are formed. In those cases for which the gradient is horizontal and the aspect vertical the plan convexity is indeterminate. These cases cannot be included in the correlations. Their maximum and minimum profile convexities are calculated and are printed with a description of the terrain. Once input is complete correlation coefficients and statistics are calculated.

Output

(a) Detailed results, output to 'detailed results file' usually dummy - output stream 3

Each line of the detailed results is as follows:
Row number, Column number, Nine altitude values, Calculated altitude, Aspect, Gradient, Profile convexity, Plan convexity. For those points for which the aspect is vertical the aspect and convexity values are assigned impossibly large arbitrary values to draw attention to the points.

(b) Calculated values for use by other programs; these are output to the calculated values file - output stream 7

Each line of calculated values is as follows:
Row number, Column number, Actual altitude, Calculated altitude, Aspect, Gradient, Profile convexity, Plan convexity, Cos of aspect, Sin of aspect. These results are in a form suitable for use by SPSS and MIDAS and are used by the other display programs.

(c) Class limits - for use in organising display programs - this is output to the 'limits file' - output stream 9

A 4x4 array containing the maximum, minimum, mean and standard deviation for each of calculated altitude, gradient, profile convexity and plan convexity.

(d) Main output - output stream 6

The first part of the output consists of a list of the calculated altitude, minimum and maximum profile curvature and a description of the type of point for all those points for which the aspect was found to be vertical. A summary of the types of points and the maximum and minimum altitude for those points is printed.

The second part of the output consists of statistics and correlation coefficients.

For all those points at which the gradient is non-zero the mean, standard deviation, skewness, kurtosis, maximum and minimum are printed for each of calculated altitude, gradient, profile convexity and plan convexity.

For the aspect angle a vector mean is printed, and also a vector mean of each aspect weighted by the sin of the gradient. Correlation coefficients for each pair of calculated altitude, gradient, profile convexity and plan convexity are printed.

A second set of statistics including as many as possible of the zero gradient points is calculated. For calculated altitude and gradient all points are included; for profile convexity and plan convexity non-zero gradient points and those for which the gradient is zero and the terrain is a horizontal plane are included (for the 'plain' points the plan convexity is taken to be zero).

Line printer density map programs OYSM and OYSMA OYSM and OYSMA each produce a variable density line printer map from a matrix of data. Each data point is represented by one printer position. The data should be in the form: row number, column number, value and the format to achieve this is part of the input data. If the number of points in a row is greater than 125 the output is divided into blocks, each of which has a maximum of 125 points; the programs will accept a row of up to 1,000 points.

OSYM produces a 6-density map.

OYSMA produces an 8-density map from data representing angles between 0° and 360°.

OYSM

Input	Data header	(20A4)
	Subtitle	(20A4)
	Name of file containing data	
	Number of columns in matrix of data	(I4)
	Format of data	
	Class boundaries for different densities	(6F8.3)

The name of the file containing the data must start in column 1 and be followed by at least one space. The data should be in the form: row number, column number, value.

The class boundaries are read in starting with the lowest. Values lower than the first class boundary and missing values are represented as blanks. Values above the 6th class boundary are printed most densely. The different densities are produced by printing (and over printing) the following symbols:

. , + , 0 , 0- , OX , OXAV

OSYMA

Input	Data header	(20A4)
	Subtitle	(20A4)
	Name of file containing data	
	Number of columns in matrix of data	(I4)
	Format of data	

The name of the file containing the data must start in column 1 and be followed by at least one space. The data should be in the form: row number, column number, value. The values are assumed to lie between 0 and 360. Any values below 0 or greater than 360 are treated as if they were 0 or 360. Missing values are represented by blanks. The values V are assumed to be measured clockwise from N. The most northerly are represented by the most dense printing and the southerly values by the least dense. East and West are of similar density but use different characters as shown below.

North V	<22.5 and >337.5	OXAV
	22.5 < V < 67.5	X+
East	67.5 < V <112.5	X
	112.5 < V <157.5	+
South	157.5 < V <202.5	.
	202.5 < V <247.5	0
West	247.5 < V <292.5	0-
	292.5 < V <337.5	OX

Slope plotting program OYPL The slope plotting program OYPL is used with the MTS plotter routines in *PLOYSYS to produce a map in which the magnitude and direction of the gradient at each grid point are represented by an arrow.

The map is 29" wide and the distance between plotted grid points depends upon the number of columns in the matrix of data. The shaft of the arrow is centred on the grid point, and is in the direction of maximum gradient. The length of the arrow depends upon the magnitude of the gradient and can be zero or from 1/5 to 5/5 of the distance between grid points. Five class boundaries are read in and if the magnitude of the gradient is less than the first class boundary only an arrow head is produced; if the gradient lies between the first and second intervals the arrow is 1/5 of the grid length, etc.

Input   Data header (20A4)
         Name of file containing calculated values
         Number of columns in matrix (I4)
         Class intervals (5F6.3)

The name of the file containing the calculated values must start in column 1 and be followed by at least one space. The program reads row number, column number, aspect and gradient from the calculated values file produced by the main program.

Class limits program OMYL The class limits program is an organisational device to ensure that, for a wide variety of altitude matrices, acceptable graphs and maps are produced automatically. The program produces scales and limits for use by other programs and writes these into appropriate positions in a master file of run commands and data. Output stream 7 is initially set to the master file (GEOD).

Input   Name of file containing limits

The limits file produced by the main program holds a 4x4 array containing the maximum, minimum, mean and standard deviation of each of the following: calculated altitude, gradient, profile convexity and plan convexity.

The MIDAS histogram program requires a minimum, maximum and class interval for each histogram. For calculated altitude which is the most likely to vary for different matrices, the class interval is chosen to give between 60 and 120 classes and the maximum and minimum are rounded up and down respectively to suitable values. The minimum, maximum and class interval are then written to a specific line in the master file in a format suitable for the histogram program.

For the line printer density maps variable limits are used for altitude and gradient. The class boundaries used are (where m is mean and sd standard deviation): m - 1.2sd, m - 0.6sd, m, m + 0.6sd, m + 1.2sd, and m and sd are rounded to give suitable class boundaries.

Output The output consists of lines of data written to appropriate lines of the master file for use by other programs.

Master file GEOD GEOD is the master file containing all the run commands and data necessary to run the terrain analysis programs. The run commands start at line -1000.

Lines 1 to 9 of the file contain the file names and data pertaining to a specific run and are used from there by several programs. Lines 1 to 9 contain the following:

1 Data header (20A4)
2 Name of file containing altitude data
3 Name of file for detailed results - usually *DUMMY*
4 Name of file for calculated values
5 Name of file for limits
6 Grid size in metres (F6.3)
7 Scaling factor to convert altitude data to metres (F10.3)
8 Number of columns in altitude matrix (I4)
9 Format for altitude data
END OF FILE

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(3) Evans I.S. (1977), 'The selection of class intervals', Trans. Inst. of British Geographers (1977) N.S.2, 1,(98-124).

Figure 1 Specimen of input to GEOD.

```
>      1      TORRIDON SCOTLAND
>      2      GGM1:TORR(4,303)
>      3      *DUMMY*
>      4      TORSEV
>      5      INTT
>      6      100.00
>      7      1.0000
>      8       100
>      9      (20F4.0)
#END OF FILE
#
```


Figure 2 Statistics produced by main program OMY8.
Data for Torridon, N.W. Scotland.

```
TORR WITH ZERO POINTS
 NO. OF ROWS=  100
STATISTICS FOR          9372POINTS WITH NON ZERO GRADIENT
        EST.ALT.       GRADIENT   PROFC      PLANC

MEAN       445.124     14.761    -0.877      1.924

SDEV       152.577     11.090     8.448     60.061

SKEW         0.728      1.009     1.145    -12.973

KURT         0.211      0.148    12.478    818.338

 MAX       979.667     54.846    76.767   1031.052

 MIN        33.444      0.581   -73.193-3122.617

 VECTOR MEAN ASPECT ANGLE            15.237
 VECTOR STRENGTH(PROPORTION)          0.180
 GRADIENT WEIGHTED VECTOR MEAN ASPECT ANGLE          4.207
 GRADIENT WEIGHTED VECTOR STRENGTH(PROPORTION)       0.017

CORRELATION COEFFS

              EST.ALT.      GRADIENT         PROFC        PLANC

EST.ALT.         1.000         0.546         0.284        0.170

GRADIENT         0.546         1.000        -0.016        0.054

PROFC            0.284        -0.016         1.000        0.148

PLANC            0.170         0.054         0.148        1.000


STATISTICS INCLUDING ZERO GRADIENT POINTS
EST ALT AND GRADIENT FOR ALL        9604    POINTS
PROFC AND PLANC FOR          9599   NON ZERO AND PLAIN POINTS
WHERE PLANC IS TAKEN AS 0.0 FOR PLAIN POINTS
        EST.ALT.      GRADIENT   PROFC      PLANC

MEAN       442.822     14.405    -0.856      1.878

SDEV       151.623     11.187     8.349     59.347

SKEW         0.759      0.999     1.151    -13.126

KURT         0.268      0.161    12.833    838.153
```

ZERO SLOPE POINTS NOT INCLUDED IN STATISTICS

EST ALT	MIN PRCFC	MAX PRCFC	
232.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
249.778	-6.653	3.597	SADDLE
396.778	-6.653	3.597	SADDLE
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
246.222	-5.348	-0.764	PIT
499.555	1.528	10.695	SUMMIT
318.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
318.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
395.000	-0.0	-0.0	PLAIN
248.000	-0.0	-0.0	PLAIN
318.000	-0.0	-0.0	PLAIN
[illegible]9.000	-0.0	-0.0	PL[illegible]
[illegible]10	[illegible]	-0.0	
		-0.[illegible]	

35[illegible]	[illegible]		[illegible]N
358.[illegible]	-0.0		LAIN
366.000	-0.0		PLAIN
366.000	-0.0	[illegible]	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
366.000	-0.0	-0.0	PLAIN
592.222	-5.348	-0.764	PIT
389.000	-0.0	-0.0	PLAIN
389.000	-0.0	-0.0	PLAIN
358.000	-0.0	-0.0	PLAIN

NO OF PLAIN POINTS IS 227
NO OF SUMMITPOINTS IS 1
NO OF SADDLEPOINTS IS 2
NO OF PIT POINTS IS 2
FOR POINTS WITH ZERO GRADIENT

MAX EST ALT = 592.222
MIN EST ALT = 232.000

Figure 3 Part of output of main program OMY8, listing points with zero gradient. Data for Torridon, N.W. Scotland.

Figure 4 Output of line printer density map program OYSM. Calculated height for Torridon, N.W. Scotland. Missing values have zero gradient.

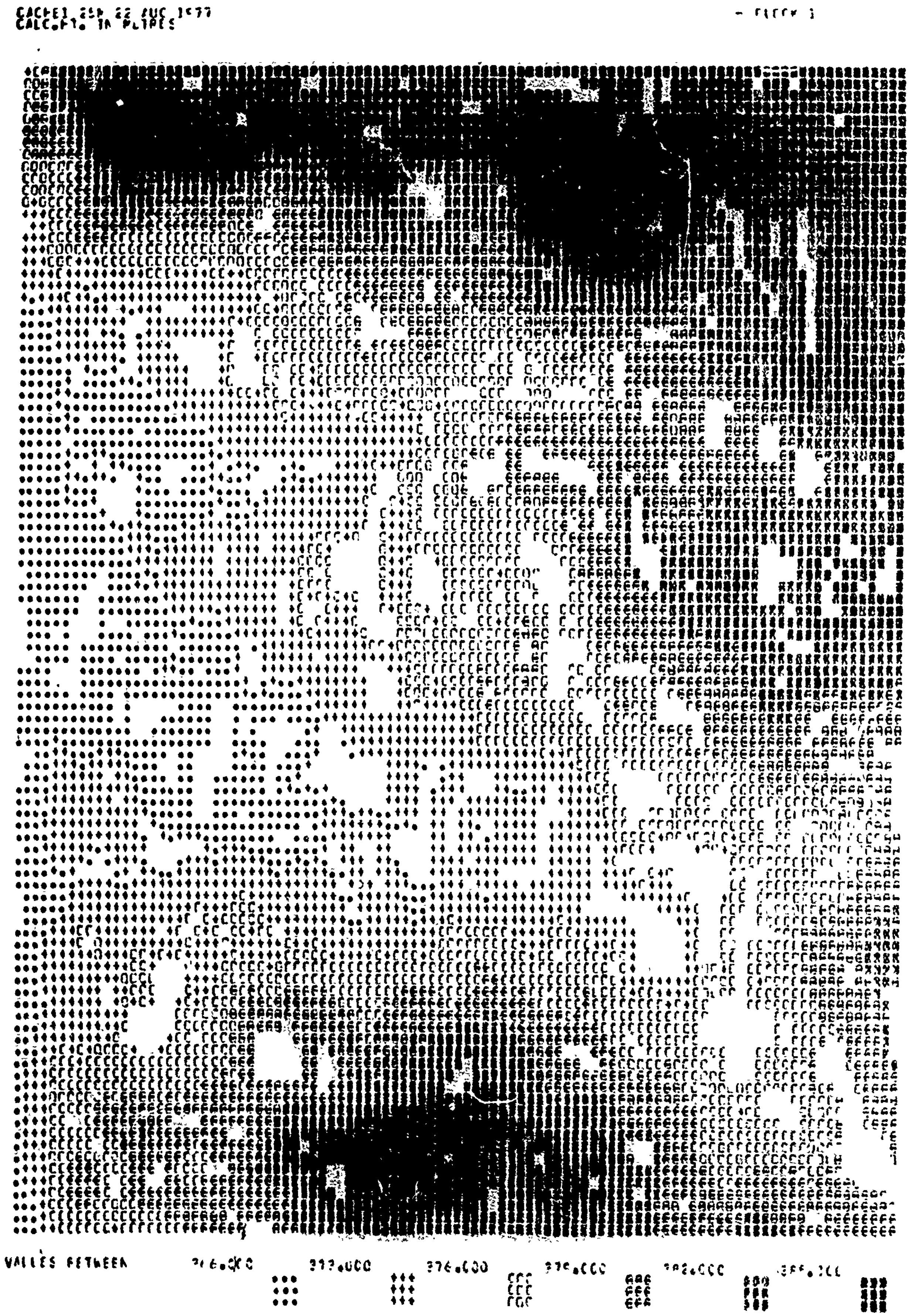


Figure 5 Output of line printer density map program OYSM. Calculated height for Cache, Oklahoma. Missing values have zero gradient.

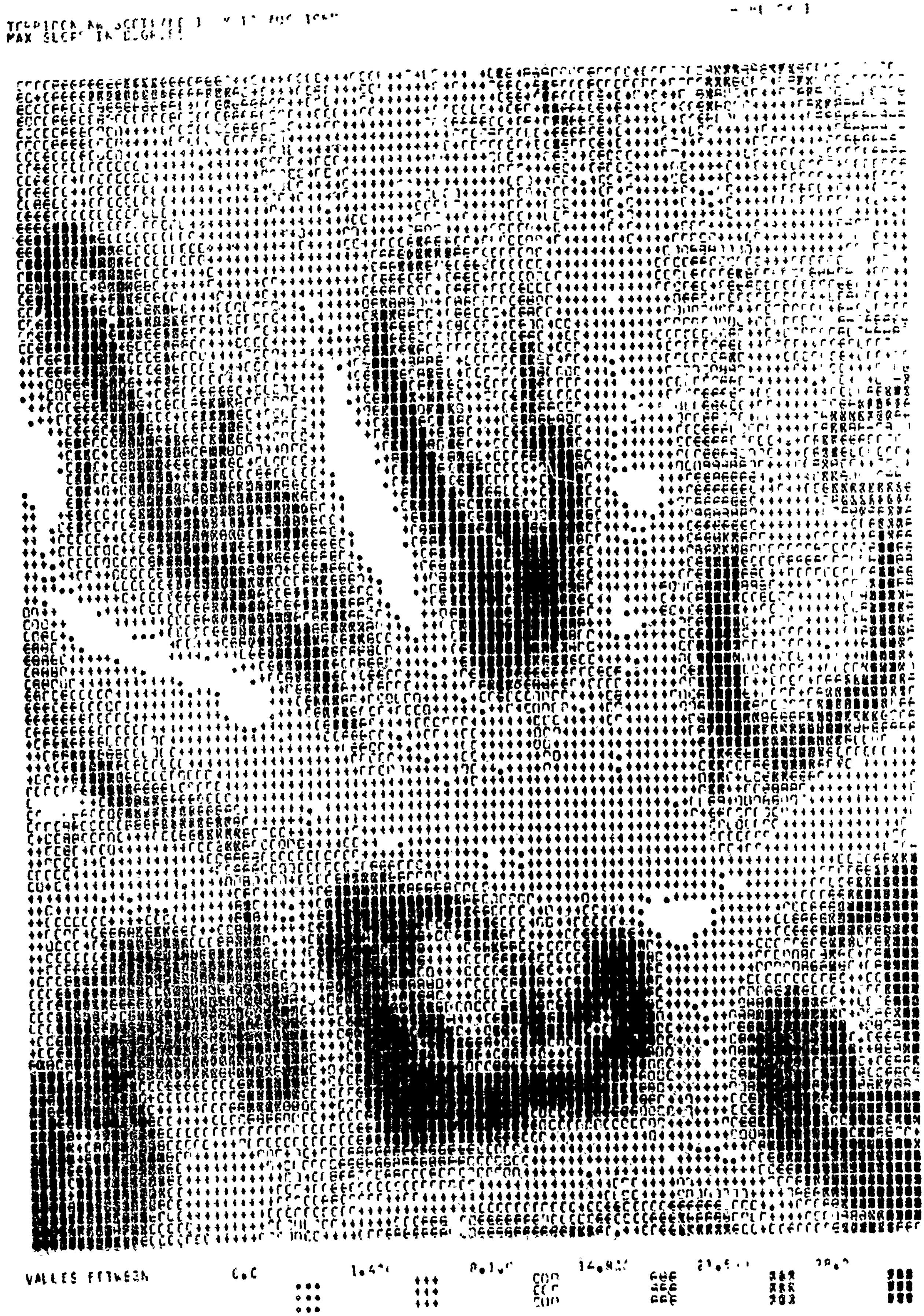


Figure 6 Output of line printer density map program OYSM. Maximum slope for Torridon, N.W. Scotland.

ASPECT

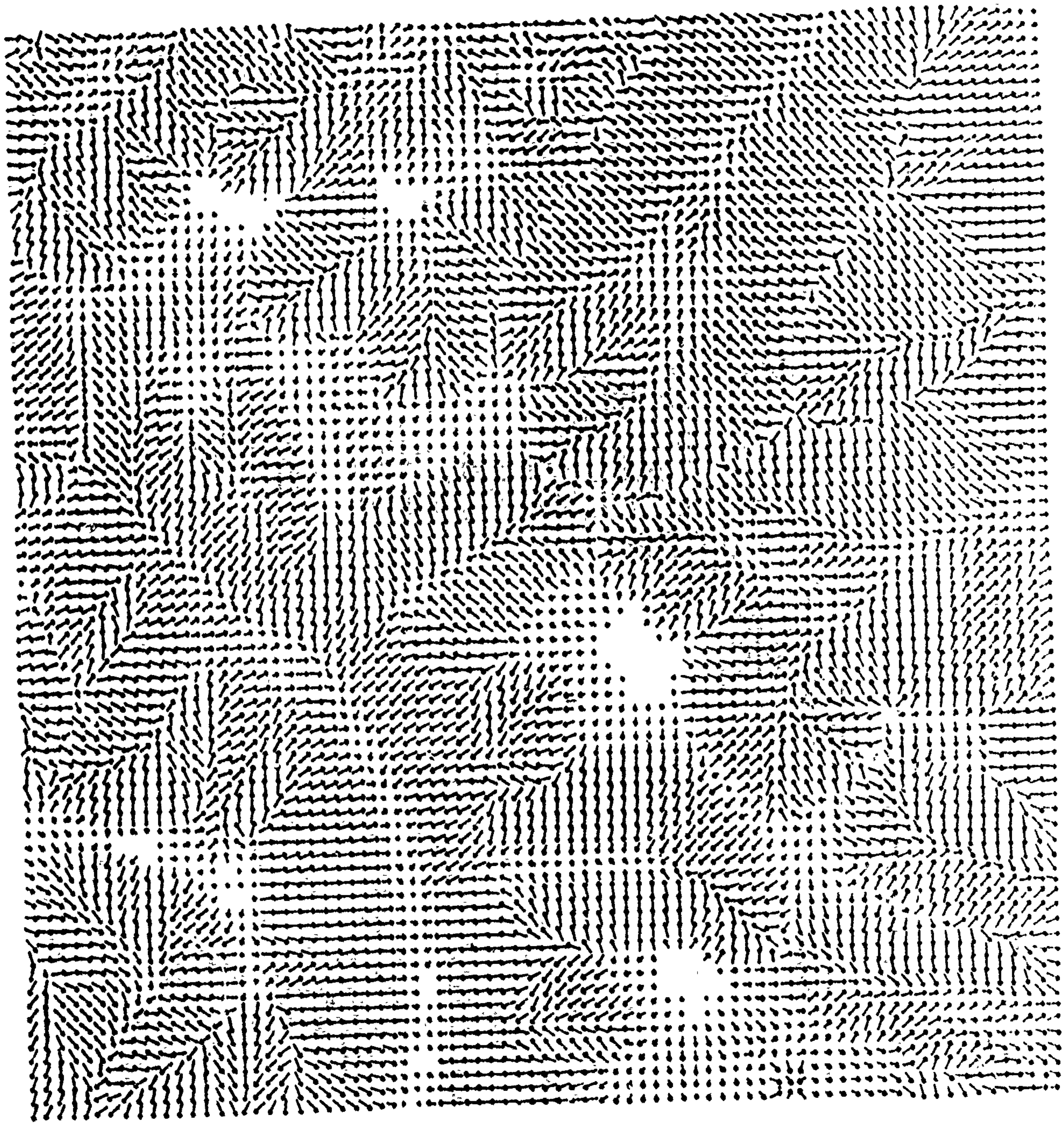
- BLOCK 1

Figure 7 Output of line printer density map program OYSMA, giving aspect. Data for Ferro, Calabria, S. Italy.

	NORTH		EAST				SOUTH				WEST		NORTH
VALUES BETWEEN	22.5		67.5		112.5		157.5		202.5		247.5		292.5	337.5

Figure 8 Output of plotter program OYPL.
Data for Nupur, N.W. Iceland.

NUPUR NW ICELAND 100M 16 AUG 1977
SLOPE VALUES 1.000 2.000 5.000 10.000 15.000



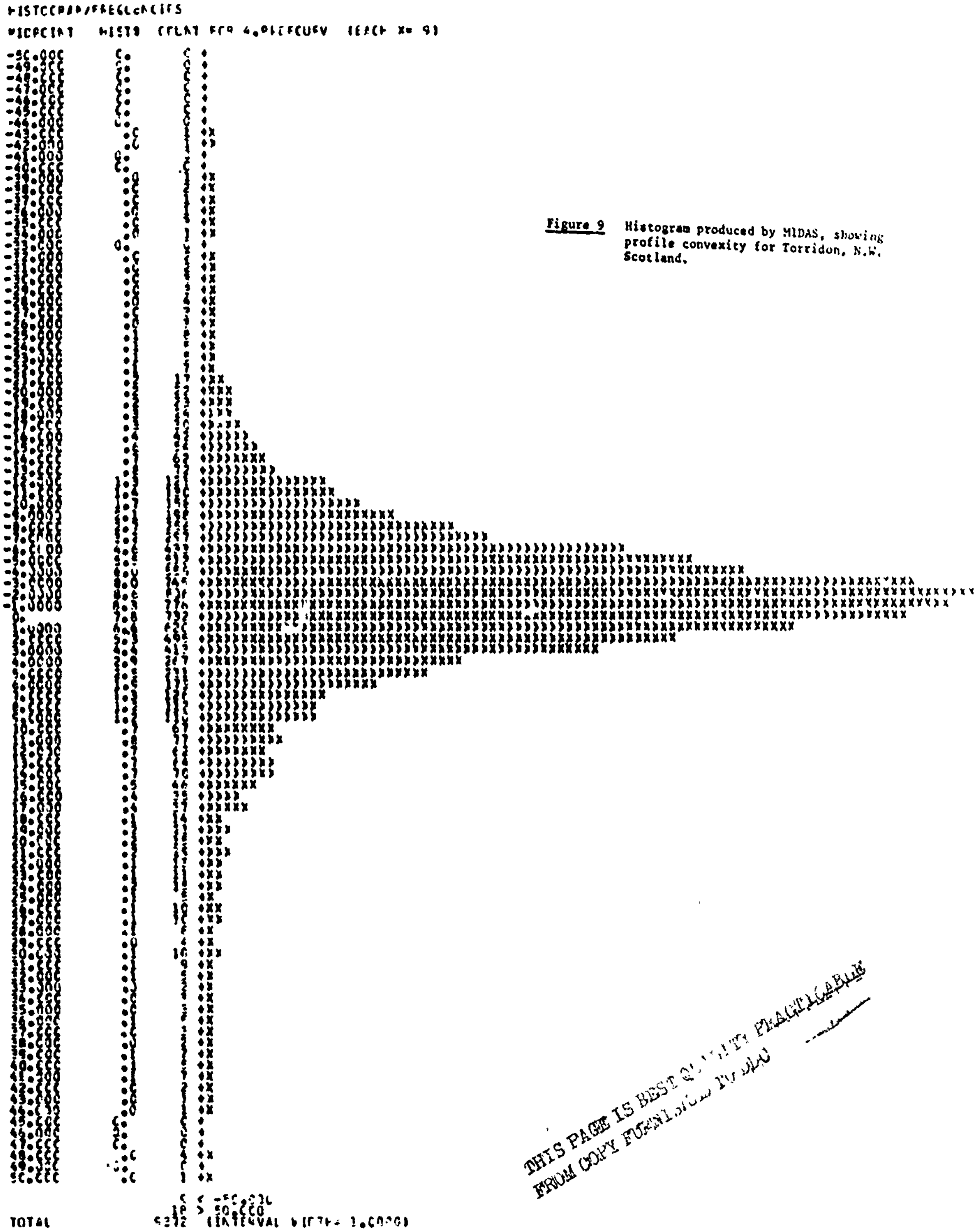


Figure 9 Histogram produced by MIDAS, showing profile convexity for Torridon, N.W. Scotland.

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FILE ACAPE (CREATION DATE = CE/23/77)

SCATTERGRAM OF (DOWN) F CALCULATED HEIGHT USING FITTED C (ACROSS) SLOPE GRADIENT OF MAX SLOPE IN DEG.

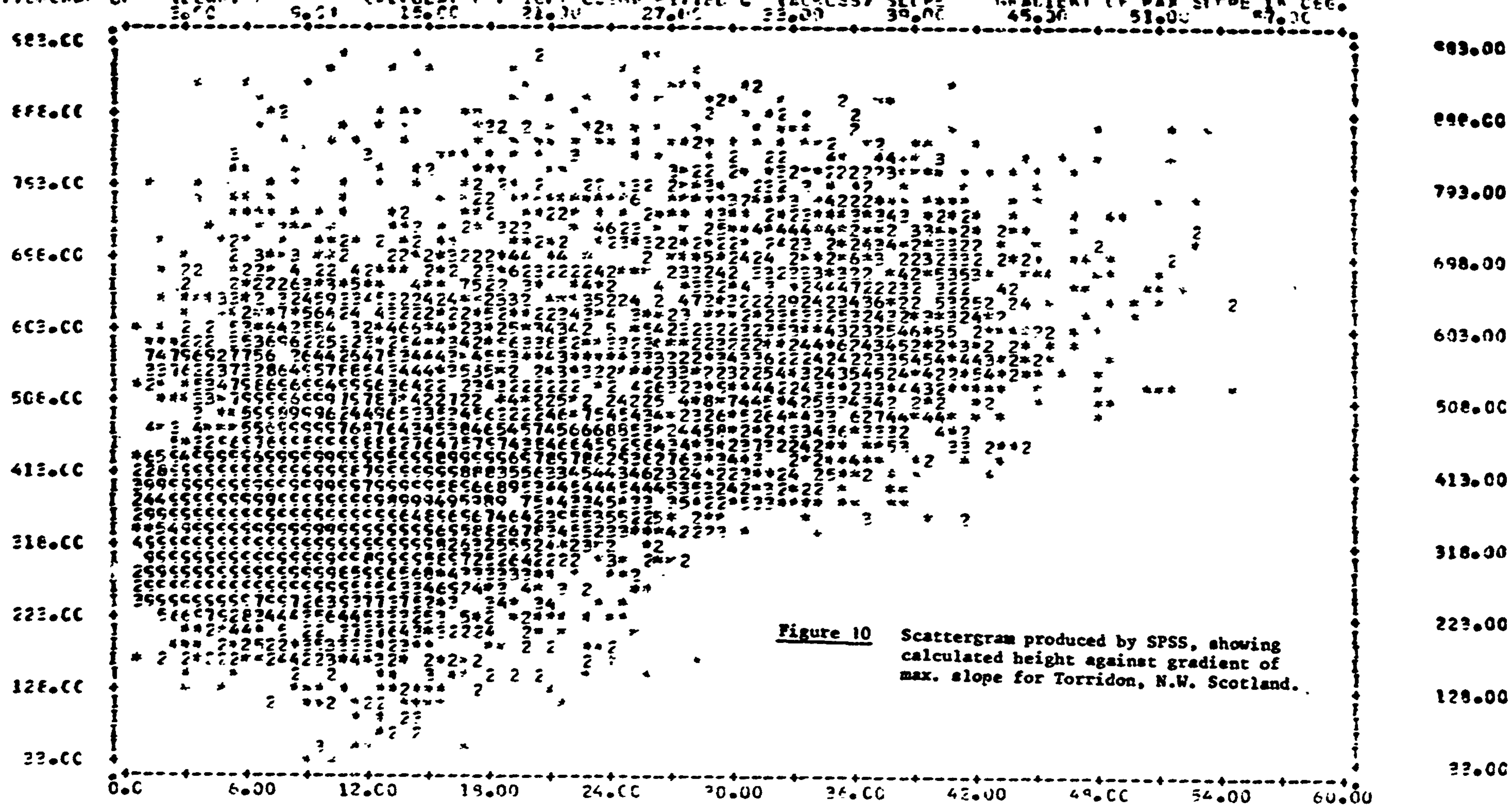

Figure 10 Scattergram produced by SPSS, showing calculated height against gradient of max. slope for Torridon, N.W. Scotland.